Asian Journal of Basic Science & Research
Volume 6, Issue 2, Pages 78-91, April-June 2024

Evaluating the suitability of groundwater for irrigation in parts of mid-Gangetic plains, Bihar

Maya[1] & Shahla Yasmin[2*]

[1,2]*Department of Zoology, Patna University, Patna, Bihar, India. Email: shahla.02apex@gmail.com*[*]

DOI: http://doi.org/10.38177/AJBSR.2024.6206

Article Received: 07 March 2024 *Article Accepted: 12 May 2024* *Article Published: 18 May 2024*

ABSTRACT

Background: Irrigation water quality is critical for crop production. The present study focuses on assessment of suitability of groundwater for irrigation purposes in four blocks of Samastipur district, Bihar lying in the mid Gangetic plains. In this district most of the people are dependent upon agriculture.

Methods: APHA standard methods were followed to analyse the major cations and anions in the water samples.

Results: Water quality assessment was done and quality parameters like TDS (Total dissolved solid) of 4.76% samples were found to be in 'high hazard' category, TH (Total hardness) of 66.66% samples were in 'very hard' category, RSC (Residual Sodium Carbonate) of 11.90% samples, MH (Magnesium Hazard) of 73.80% samples and KI (Kelly's Index) of 4.76% samples were in 'unsuitable' category. The results suggest that the groundwater used for irrigation in this area may be harmful for crop health and productivity.

Conclusion: Some of the parameters like TDS, TH, RSC, MH and KI values of water samples were found beyond standard limits which may be harmful to crop health and productivity. However, the maximum number of groundwater samples were found in "Medium salinity and low SAR values" (99.97%) category, suggesting the water is suitable for crops. Also, Wilcox plot showed 95.23% % samples were in "Excellent to good" and "Good to permissible" categories suggesting the water may be suitable for irrigation.

Keywords: Groundwater; Agriculture; Samastipur; Residual Sodium Carbonate; Soluble Sodium Percentage (SSP); Sodium Absorption Ratio (SAR); Na% (Sodium Percent); MH (Magnesium hazard); KR (Kelly's ratio); PI (Permeability index).

1. Introduction

The suitability of water for irrigation is an important aspect of agricultural practices (Hasan et al., 2020). Contaminants in groundwater, such as heavy metals, high salinity, and excessive nutrients, have significantly deteriorated the quality of water used for agricultural purposes. This degradation has resulted into serious threats to crop health, leading to low productivity and poor crop yields posing a threat to food security (Mukherjee, 2021). The infiltration of pollutants into groundwater sources can result from various activities, including industrial discharge, agricultural runoff, and improper waste disposal. As groundwater serves as a primary source for irrigation in many regions, its contamination disrupts the delicate balance of nutrients required for optimal plant growth. Consequently, farmers face challenges in maintaining soil health and achieving sustainable crop production.

Some of the parameters like pH level, Electrical Conductivity (EC), Total Dissolved Solids (TDS), total hardness (TH), Chloride Hazard (Cl^-), Soluble Sodium Percentage (SSP), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Na% (Sodium Percent), MH (Magnesium hazard), KR (Kelly's ratio) and PI (Permeability index) are used to assess the irrigation water quality (Adimalla et al., 2020; Hasan et al., 2020; Qadir et al., 2021; Singh et al., 2008).

This study attempted to assess the groundwater suitability for irrigation purposes considering above parameters in four blocks of Samastipur district, Bihar lying in the mid Gangetic plains. This may be helpful in sustainable mitigation and management of groundwater resource of the study area.

Asian Journal of Basic Science & Research
Volume 6, Issue 2, Pages 78-91, April-June 2024

2. Study Area

The study area is agriculture based and comes under the agro-ecological zone-I of the Bihar state i.e. North-West Alluvial plains. It is noted for its fertile alluvial soil and *rabi* crops. The soil is sandy loam with moderately high organic matter which makes the soil fertile and because of its fertility it is suitable for cultivation of crops like tobacco, maize, rice, wheat, vegetables, and spices.

Present study focused on 42 locations in four different blocks of the study area namely Patori, Mohuddinagar, Mohanpur and Vidyapatinagar of Samastipur district, Bihar (Figure 1). The coordinates and villages are represented in Table 1. Samples were coded as SPU1 to SPU46 during post-monsoon season (POM). Location (Latitude-longitude) was marked with Garmin GPS machine.

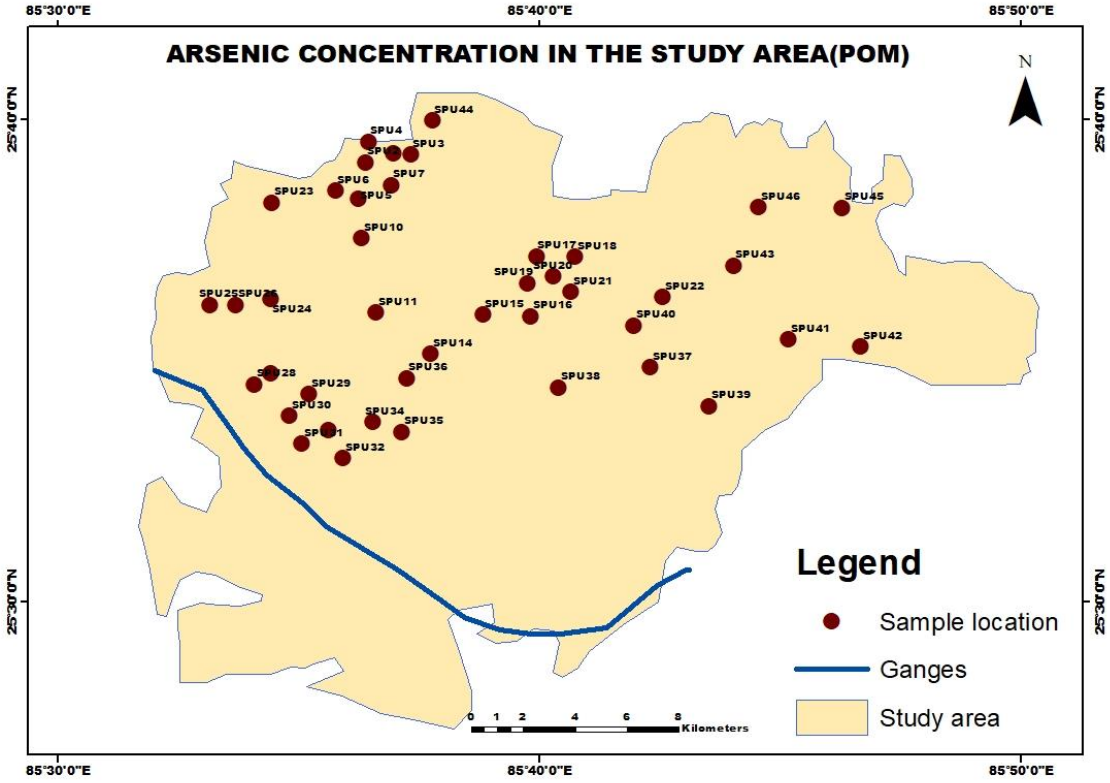

Figure 1. Study area with sample locations

Table 1. Study area codes, blocks, latitude and longitude

Code	Block	Latitude	Longitude
SPU1	Patori	25.6582	85.6105
SPU2	Patori	25.6596	85.6076
SPU3	Patori	25.6586	85.6075
SPU4	Patori	25.6586	85.6075
SPU5	Patori	25.6420	85.5986

SPU6	Patori	25.6417	85.5961
SPU7	Patori	25.6437	85.6155
SPU10	Patori	25.6337	85.5897
SPU11	Patori	25.6253	85.6051
SPU14	Patori	25.5853	85.6290
SPU15	Mohuddinagar	25.6398	85.5833
SPU16	Mohuddinagar	25.6027	85.5563
SPU17	Mohuddinagar	25.6023	85.5527
SPU18	Mohuddinagar	25.6023	85.5542
SPU19	Mohuddinagar	25.5988	85.6471
SPU20	Mohuddinagar	25.5983	85.6636
SPU21	Mohuddinagar	25.6114	85.6738
SPU22	Patori	25.6123	85.6723
SPU23	Patori	25.6120	85.6716
SPU24	Patori	25.6068	85.6775
SPU25	Patori	25.5991	85.7012
SPU26	Mohanpur	25.5950	85.6993
SPU27	Mohanpur	25.5806	85.7051
SPU28	Mohanpur	25.5737	85.6734
SPU29	Mohanpur	25.5672	85.7254
SPU30	Mohanpur	25.5903	85.7529
SPU31	Mohanpur	25.5745	85.5677
SPU32	Mohanpur	25.5747	85.5681
SPU33	Mohanpur	25.5594	85.5822
SPU34	Mohanpur	25.5640	85.5803
SPU35	Mohanpur	25.5593	85.5823
SPU36	Mohuddinagar	25.5594	85.5941
SPU37	Mohuddinagar	25.5589	85.5938

SPU38	Mohuddinagar	25.5618	85.6092
SPU39	Mohuddinagar	25.5584	85.6192
SPU40	Mohuddinagar	25.5769	85.6207
SPU41	Vidyapatinagar	25.5878	85.7779
SPU42	Vidyapatinagar	25.6271	85.7387
SPU43	Vidyapatinagar	25.6736	85.6195
SPU44	Vidyapatinagar	25.6358	85.7715
SPU45	Vidyapatinagar	25.6358	85.7715
SPU46	Vidyapatinagar	25.6359	85.7439

3. Materials and Methods

Sample collection was done in the month of October, 2021. APHA standard methods (APHA, 2017) were followed to analyse the major cations and anions in the water samples. pH, Electrical Conductivity (EC) and ORP (oxidation reduction potential) were measured by Eutech portable pH metre, EC metre and ORP meter respectively on the spot. Volumetric titration method was followed using standard 0.02 N or (N/50) EDTA solution for obtaining total hardness (TH), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The chloride (Cl^{-}) was estimated by titrating with 0.02N $AgNO_3$ standard. The carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) were analysed by titrating with 0.02 N H_2SO_4. Na^{+} and K^{+} were analysed by flame photometer (Systronics128).

Following formulae were used for calculation:

- SAR (Sodium absorption Ratio) = Na+/√(Ca2++Mg2+)/2 (Richards, 1954).
- SSP% (Soluble Sodium Percentage) = [(Na+)/ (Ca2++Mg2++Na+)] *100 (Todd 1980).
- RSC (Residual Sodium Carbonate) = (HCO3-+ CO32-) – (Ca2+ + Mg2+) (Raghunath1987).
- Na% (Sodium Percent) = ((Na++K+) / (Ca2++Mg2++Na++K+)) *100 (Wilcox, 1955).
- KR (Kelly's ratio) = Na+/Ca2++Mg2+ (Kelly 1963).
- MH (Magnesium hazard) = (Mg)2+ / (Ca2++Mg2+) *100 (Raghunath 1987).
- PI (Permeability index) = ((Na++ (√HCO3-) / (Ca2++Mg2++Na2+)) *100 (Doneen 1964).

The Wilcox Plot and USSL (United States Salinity Laboratory) diagrams were used to assess the water quality and its suitability for agricultural uses.

Wilcox Plot: Sodium percentage (Na%) was plotted against the Electrical Conductivity (EC) of water. Different zones on the plot represented categories like excellent, good, permissible, doubtful, and unsuitable for irrigation.

USSL Diagram: Scatter plot was plotted between SAR and Electrical conductivity. It represented sodium hazard – S1 (Low), S2 (Medium), S3 (High), S4 (Very high) zones on y-axis and Salinity hazard – C1 (Low), C2 (Medium), C3 (High), C4 (Very high) zones on x-axis.

4. Results and Discussion

The pH level in the water samples ranged from 6.15 to 7.50 (Mean=6.98± 0.035). In 50% water samples, it was found to be of "EXCELLENT" category, in 47.61% samples it was of "GOOD" category and in 4.76% samples, pH level was below "GOOD" category (slightly acidic - not suitable for agriculture).

Electrical Conductivity (EC) varied from 161.90 to 2230.00 µS/cm (Mean=921.62±63.956 µS/cm). EC of 28.57% samples was found to be of "EXCELLENT" category. In the remaining 71.42% samples, it was of "GOOD" category.

Total Dissolved Solids (TDS) ranged from 113.33 to 1561.00 mg/L (Mean=645.13± 44.769mg/L). TDS value in 2.38% samples was under "VERY LOW HAZARD" category, in 23.80% samples, it was under "LOW HAZARD" category, in 71.42% samples, it was under "MEDIUM HAZARD CATEGORY" and in 4.76 % samples it was found to be under "HIGH HAZARD" category which is unsuitable for crops and may lead to reduced water uptake by plants resulting in retarded growth of plants (Sreedevi et al., 2019).

Total Hardness (TH) levels ranged from 76.00 to 640.00 mg/L (Mean=344.31±17.333mg/L). The value of TH in 4.76% of the water samples was under "MODERATE" category, in 28.57% samples, it was found to be under "HARD" category and in remaining 66.66% samples it was found to be under "VERY HARD" category, Increased level of TH of irrigation water may impact soil structure and irrigation system performance and enhance the sodicity of soil (Rasouli et al., 2012) which is unsuitable for crops.

Chloride concentrations ranged widely from 7.09 to 207.78 mg/L (Mean=58.7±12.817 mg/L). In 85.71% samples, it was under "HIGHLY SUITABLE" category, in 11.90% samples it was under "SUITABLE" category and in the remaining 2.38% samples, it was below "SUITABLE" category.

The Sodium Adsorption Ratio (SAR) values varied from 0.08 to 4.19 (Mean=1.22±2.072). SAR values were of "EXCELLENT" category in 90.47% samples. In the remaining 9.52% samples, it was under "GOOD" category.

Sodium Saturation Percentage (SSP%) ranged from 2.58% to 59.99%. (Mean=22.25± 0.160%). The values of 50% samples were under "EXCELLENT" category, 35.71% samples were under "GOOD" category and the remaining 14.28% water samples were under "FAIR" category.

Residual Sodium Carbonate (RSC) values ranged from -4.73 to 3.76 (Mean=0.51± 0.239). 73.80% samples were under "GOOD" category, 14.28% samples were under "DOUBTFUL" category, and the rest of the 11.90% samples was under "UNSUITABLE" category which may result into alkaline conditions that affects nutrient availability and microbial activity (Shukla and Saxena, 2020)

Percentage Sodium (%Na) varied from 3.81% to 60.47%, (Mean=23.68±2.142 %). In 50% samples Na% was under "EXCELLENT" category, in 35.71% samples it was under "GOOD" category, in 11.90% samples, it was under

"PERMISSIBLE" category and in 2.38% samples, it exceeded the "PERMISSIBLE" category which is not suitable for crops. Excess of Na^{+} ions causes displacement of Ca^{+2} and Mg^{+2} in soil (Chaudhary and Satheeshkumar, 2018) thereby decreasing the nutrient value of soil.

Kelly's Index (KI) values ranged from 0.03 to 1.50 (Mean=0.34± 0.046). In 95.23% samples. KI value was found "SUITABLE" and in the remaining 4.76% samples it was found to be "UNSUITABLE" for irrigation. This may cause alkali hazard to crops (Ramesh and Elango, 2012).

Permeability Index (PI) varied from 8.71 to 11.77, (Mean=10.28±1.736). PI value in 4.76% samples was found to be "PERFECTLY SUITABLE" and in remaining 95.23% samples it was found to be "MODERATELY SUITABLE."

Magnesium hazard (MH) ranged from 5.97 to 93.24 mg/L (Mean=60.64±2.771 mg/L). In 26.19% samples, it was found to be "SUITABLE" and in remaining 73.80% samples it was found "UNSUITABLE" for crops which is a matter of concern as excessive MH in soil makes the soil alkaline and unsuitable for crops (Narsimha and Sudarshan, 2013).

Table 2 shows the irrigation water quality parameters and their suitability classification. Irrigation water quality data for each sample in the study area is shown in the Supplementary Table.

Table 2. Irrigation water quality parameters and their suitability classification

Parameters	**Range**	**Suitability classification**	**Number and Percentage**	**Location code**	**References**
pH	7–8	Excellent	20, 47.61	SPU1 SPU3 SPU4 SPU6 SPU10 SPU14 SPU17 SPU18 SPU21 SPU22 SPU24 SPU25 SPU28 SPU33 SPU35 SPU36 SPU39 SPU40 SPU45 SPU46	(Ayers & Westcot, 1985; Simsek & Gunduz, 2007)
	6.5–7	Good	21, 50.00	SPU2 SPU5 SPU7 SPU11 SPU15 SPU16 SPU19 SPU20 SPU23 SPU26 SPU27 SPU29-32 SPU34 SPU37 SPU38 SPU41 SPU43 SPU44	

EC (µS/cm)	< 700	Excellent	12, 28.57	SPU10 SPU11 SPU14 SPU16 SPU21 SPU25 SPU26 SPU33 SPU35 SPU36 SPU39 SPU46	(Ayers & Westcot, 1985)
	700-3000	Good	30, 71.42	SPU1-7 SPU15 SPU17-20 SPU22 SPU23 SPU24 SPU27-32 SPU34 SPU37 SPU38 SPU40 SPU41 SPU42 SPU43 SPU44 SPU45	
TDS (mg/l)	<160	Very low hazard	1, 02.38	SPU46	(Hopkins et al., 2007)
	160-480	Low hazard	10, 23.80	SPU10 SPU11 SPU14 SPU18 SPU20 SPU26 SPU31 SPU38 SPU40 SPU46	
	480-1280	Medium hazard	30, 71.42	SPU1-7 SPU15 SPU19 SPU17-21 SPU22 SPU23 SPU27-32 SPU34 SPU37 SPU38 SPU40-45	
	1280-1920	High hazard	2, 4.76	SPU6 SPU17	
TH (mg/l)	75–150	Moderate	1, 2.38	SPU46	Sawyer and McCarty (1967)
	150–300	Hard	13, 30.95	SPU10 SPU11 SPU14-17 SPU22 SPU25 SPU26 SPU33 SPU36 SPU37 SPU40	
	> 300	Very hard	28, 66.66	SPU1-7 SPU18 SPU19 SPU20 SPU21	

				SPU23 SPU24 SPU27-32 SPU34 SPU35 SPU38 SPU39 SPU41-45	
Cl^- (mg/L)	< 140	Highly suitable	36, 85.71	SPU1-5 SPU10-18 SPU20-23 SPU25 SPU26 SPU27 SPU29-39 SPU41-46	Ayers and Westcot (1985), Simsek and Gunduz (2007)
	140–350	Suitable	5, 11.90	SPU7 SPU19 SPU24 SPU28 SPU40	
SAR	< 3	Excellent	38, 90.47	SPU1-6 SPU10 SPU11 SPU14-23 SPU25-36 SPU38 SPU39 SPU41-46	Ayers and Westcot (1985)
	3–9	Good	4, 09.52	SPU7 SPU24 SPU37 SPU40	
	> 9	Permissible	0	0	
SSP%	<20	Excellent	21, 50.00	SPU4 SPU5 SPU10 SPU14 SPU16 SPU21 SPU23 SPU25 SPU26 SPU27 SPU30-33 SPU35 SPU39 SPU41 SPU42 SPU44 SPU45 SPU46	Wilcox (1955)
	20-40	Good	15, 35.71	SPU1-3 SPU6 SPU11 SPU15 SPU17 SPU18 SPU20 SPU22 SPU29 SPU34 SPU36 SPU38 SPU43	

	40-80	Fair	6, 14.28	SPU7 SPU19 SPU24 SPU28 SPU37 SPU40	
	>80	Poor	0		
RSC	< 1.25	Good	31, 73.80	SPU1 SPU2 SPU4 SPU6 SPU10 SPU14 SPU16 SPU17 SPU19 SPU20-23 SPU25-36 SPU39 SPU41 SPU42 SPU44 SPU46	Eaton (1950)
	1.25–2.5	Doubtful	6, 14.28	SPU3 SPU11 SPU15 SPU18 SPU43 SPU45	
	> 2.5	Unsuitable	5, 11.90	SPU7 SPU24 SPU37 SPU38 SPU40	
KI	< 1	Suitable	40, 95.23	All except SPU37 SPU40	Kelley (1940)
PI	> 75 (Class I)	Perfectly suitable	2, 04.76	SPU37 SPU40	
	75–25 (Class II)	Moderately suitable	40, 95.23	All except SPU37 SPU40	Doneen (1964)
	< 25 (Class III)	Unsuitable	2, 04.76	SPU37 SPU40	
MH	< 50	Suitable	11, 26.19	SPU1 SPU14-17 SPU22 SPU24 SPU34 SPU36 SPU38 SPU46	Szabolcs and Darab (1964)
	> 50	Unsuitable	31, 73.80	SPU2-7 SPU10 SPU11 SPU18-21 SPU23 SPU25-33 SPU35 SPU37 SPU39-45	

*Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total hardness (TH), Chloride Hazard (Cl^-), Soluble Sodium Percentage (SSP), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Na% (Sodium Percent), MH (Magnesium hazard), KR (Kelly's ratio) and PI (Permeability index).

In USSL diagram (Figure 2) it can be observed that 97.61% samples fall in "C2S1" and "C3S1" region which represents "Medium salinity and low SAR values". One sample was found in "C1S1" region which represents "Low salinity and low SAR value".

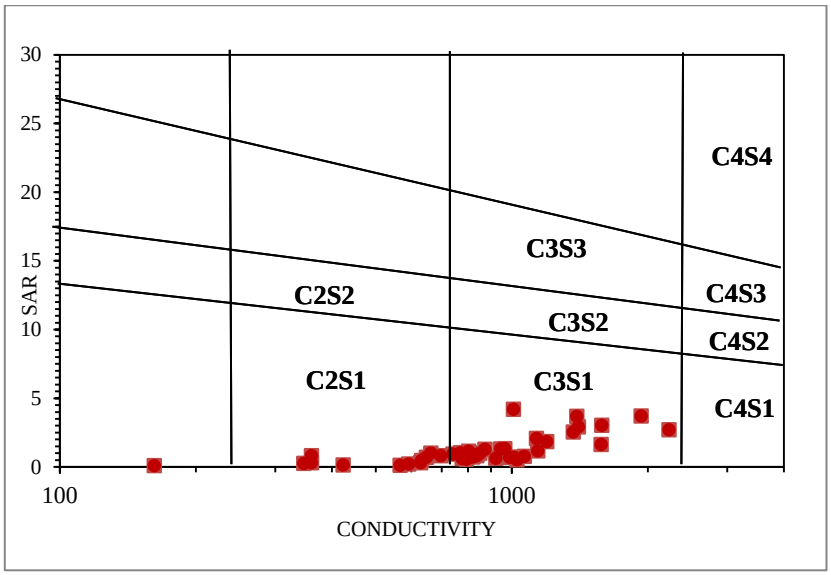

Figure 2. USSL diagram for assessment of water quality for irrigation

In Wilcox plot (Figure 3) 95.23% samples fell in "Excellent to good" and "Good to permissible "category. However, one sample was in "Doubtful to unsuitable category" and one sample in "Permissible to doubtful category".

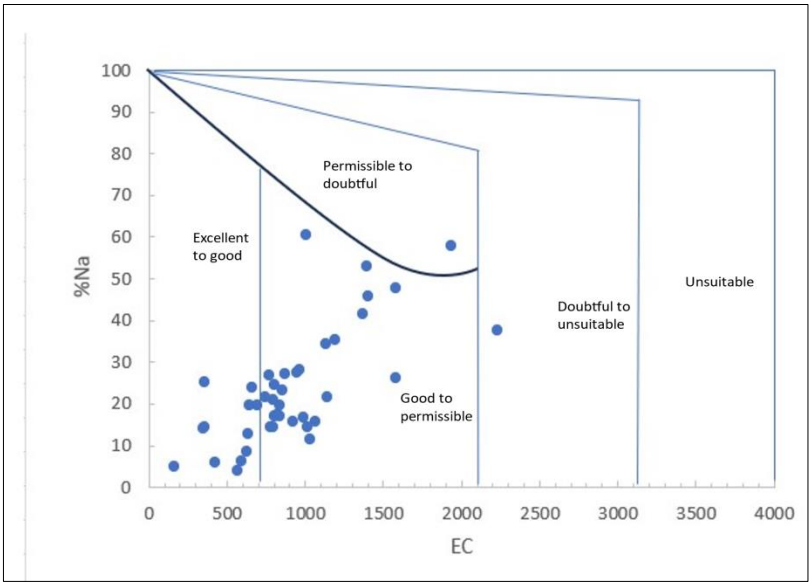

Figure 3. Wilcox plot to assess the water quality for irrigation

5. Conclusion

Irrigation water quality parameters including TDS of 4.76% samples were in 'high hazard' category, TH of 66.66% samples were in 'very hard' category, RSC of 11.90% samples, MH of 73.80% samples and KI of 4.76% samples were in 'unsuitable' category.

The maximum number of groundwater samples were found in "Medium salinity and low SAR values" (99.97%) category, as represented by USSL diagram for classification of irrigation water. This condition was found to be suitable for crops. Also, Wilcox plot showed 95.23% % samples were in "Excellent to good" and "Good to permissible" categories and may be suitable for irrigation.

The groundwater in the study area was fortunately found to be suitable for irrigation of crops. Still, it is suggested that a regular monitoring of groundwater quality should be done. Moreover, the farmers should also be apprised about sustainable agricultural practices and the importance of maintaining clean groundwater resources that can help to enhance the agricultural productivity.

Declarations

Source of Funding

This study did not receive any grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All the authors took part in literature review, analysis and manuscript writing equally.

Authors' contributions

Maya did the field and lab work and data analysis. Maya prepared the original draft of the Ms. Shahla Yasmin conceptualized, supervised, and edited the MS. All the authors read and approved the final manuscript.

References

Adimalla, N., Dhakate, R., Kasarla, A., & Taloor, A.K. (2020). Appraisal of groundwater quality for drinking and irrigation purposes in Central Telangana, India. Groundwater for Sustainable Development, 10: 100334. https://doi.org/10.1016/j.gsd.2020.100334.

APHA (2017). Standard Methods for examination of water and wastewater, 23rd edition. In APHA (American Public Health Association), American Water Works Association, and Water Environment Federation.

Ayers, R.S., & Westcot, D.W. (1985). Water Quality for Agriculture. FAO of the United Nations, Rome, Italy, 29: 174.

Chaudhary, V., & Satheeshkumar, S. (2018). Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. Applied Water Science, 8: 1–17. https://doi.org/10.1007/s13201-018-0865-9.

Doneen, L.D. (1964). Notes on Water Quality in Agriculture. Department of Water Science and Engineering, University of California, Davis, Pages 400.

Eaton, F.M. (1950). Significance of Carbonate in Irrigation Water. Soil Science, 67: 112–13.

Gomathy, M., Kalaiselvi, K., & Sakthivel, V. (2023). Future of farming. In Advanced Technologies for Smart Agriculture, Pages 359–381. https://doi.org/10.1201/9781032628745-17.

Hasan, M.Y., Khan, M.F.H., Islam, M.K., Hasan, M.M., Hossain, M.A., Monir, M.U., Samad, M.A., & Ahmed, M.T. (2020). Dataset on the evaluation of hydrochemical properties and groundwater suitability for irrigation purposes: South-western part of Jashore, Bangladesh. Data in Brief, 32: 106315.

Hopkins, B.G., Horneck, D.A., Stevens, R.G., Ellsworth, J.W., & Sullivan, D.M. (2007). Managing irrigation water quality for crop production in the Pacific Northwest. Pacific Northwest Extension.

Kaur, T., Bhardwaj, R., & Arora, S. (2017). Assessment of groundwater quality for drinking and irrigation purposes using hydrochemical studies in Malwa region, southwestern part of Punjab, India. Applied Water Science, 7: 3301–3316. https://doi.org/10.1007/s13201-016-0476-2.

Kelly, W.P. (1963). Use of Saline irrigation Water. Soil Science, 95(4): 355–39.

Kelley, W.P. (1940). Permissible composition and concentration of irrigated waters. Proceedings of the American Society of Civil Engineers, 66: 607.

Mukherjee, D. (2021). Food Security under the Era of Climate Change Threat. Journal of Advanced Agriculture & Horticulture Research, 1(1): 1–4. https://doi.org/10.55124/jahr.v1i1.78.

Mukhopadhyay, B.P., Chakraborty, A., Bera, A., & Saha, R. (2022). Suitability assessment of groundwater quality for irrigational use in Sagardighi block, Murshidabad district, West Bengal. Applied Water Science. 12(3): 38. https://doi.org/10.1007/s13201-021-01565-4.

Narsimha, A., & Sudarshan, V. (2013). Groundwater and Its assessment for Irrigation purpose in Hanmakonda Area, Warangal District, Andhra Pradesh, India. International Journal of Research in Chemistry and Environment, 3(2): 196–200.

Qadir, M., Sposito, G., Smith, C.J., & Oster, J.D. (2021). Reassessing irrigation water quality guidelines for sodicity hazard. Agricultural Water Management, 255: 107054. https://doi.org/10.1016/j.agwat.2021.107054.

Raghunath, H.M. (1987). Groundwater. Wiley Eastern Ltd., New Delhi, 563.

Ramesh, K., & Elango, L. (2012). Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India. Environmental Monitoring and Assessment, 184: 3887–3899. https://doi.org/10.1007/s10661-011-2231-3.

Rasouli, F., Pouya, A.K., & Ali Mohammad Cheraghi, S. (2012). Hydrogeochemistry and water quality assessment of the Kor-Sivand Basin, Fars province, Iran. Environmental Monitoring and Assessment. 184: 4861–4877. https://doi.org/10.1007/s10661-011-2308-z.

Richards, L.A. (1954). Diagnosis and Improvement of Saline and Alkaline Soils. Agriculture Handbook No.60, USDA, Washington, In Soil Science Society of America Journal.

Sawyer, C.N., & McCarty, D.L. (1967). Chemistry of Sanitary Engineers, 2nd Ed. McGraw-Hill, NY, Pages 518.

Shukla, S., & Saxena, A. (2020). Groundwater quality and associated human health risk assessment in parts of Raebareli district, Uttar Pradesh, India. Groundwater for Sustainable Development, 10: 100366. https://doi.org/10.1016/j.gsd.2020.100366.

Simsek, C., & Gunduz, O. (2007). IWQ Index: A GIS-integrated technique to assess irrigation water quality. Environmental Monitoring and Assessment, 128: 277–300. https://doi.org/10.1007/s10661-006-9312-8.

Singh, A.K., Mondal, G.C., Kumar, S., Singh, T.B., Tewary, B.K., & Sinha, A. (2008). Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin, India. Environmental Geology, 54(4): 745–758. https://doi.org/10.1007/s00254-007-0860-1.

Sreedevi, P.D., Sreekanth, P.D., Ahmed, S., & Reddy, D.V. (2019). Evaluation of groundwater quality for irrigation in a semi-arid region of South India. Sustainable Water Resources Management, 5: 1043–1056. https://doi.org/10.1007/s40899-018-0279-8.

Szabolcs, I., & Darab, C. (1964). The influence of irrigation water of high sodium carbonate content of soil. In Proceedings of 8th International Congress Issue Transactions, 2: 80.

Todd, D.K. (1980). Groundwater Hydrology. John Wiley and Sons Publication, 3rd Ed., New York.

Wilcox, L.V. (1955). Classification and Use of Irrigation Water. Washington: US Department of Agriculture, Circular No.969, Pages 19.

Supplementary Table: Irrigation water quality parameters in the study area during POM

Code	Block	Village	pH	EC	TDS	TH	Cl^-	S S P%	SAR	RSC	%Na	K I	MH	P I
SPU1	Patori	Jorpura	7.210	804.000	562.800	335.000	21.270	23.781	1.142	1.164	24.623	0.312	5.969	55.683
SPU2	Patori	Jorpura	6.900	1578.000	1104.600	600.000	129.895	24.908	1.625	-3.630	26.030	0.332	74.997	43.012
SPU3	Patori	Jorpura	7.080	793.000	555.100	320.000	14.180	20.973	0.949	1.364	21.025	0.265	79.685	55.382
SPU4	Patori	Jorpura	7.010	839.000	587.300	370.000	14.180	18.641	0.881	1.070	19.590	0.229	82.430	50.640
SPU5	Patori	Chaksalem	6.870	804.000	562.800	370.000	21.270	16.599	0.766	0.263	17.016	0.199	93.242	47.801
SPU6	Patori	Chaksalem	7.100	2230.000	1561.000	640.000	453.760	34.860	2.708	-4.733	37.621	0.535	70.309	49.314
SPU7	Patori	Chakarman	6.690	1583.000	1108.100	380.000	173.705	43.728	3.029	2.281	47.616	0.777	53.943	67.004
SPU10	Patori	Sirdilpur	7.270	361.000	252.700	170.000	14.180	10.435	0.304	-0.073	14.502	0.117	55.878	58.489
SPU11	Patori	Bahadurpur	6.900	663.000	464.100	265.000	17.725	23.436	0.997	1.355	23.738	0.306	66.034	60.705
SPU14	Patori	Dumduma	7.010	424.000	296.800	220.000	17.725	4.520	0.140	-0.569	5.857	0.047	45.450	46.997
SPU15	Mohuddinagar	Nandini	6.860	874.000	676.200	210.000	28.360	26.831	1.270	1.260	27.194	0.367	49.996	59.690
SPU16	Mohuddinagar	Rajajaan	6.790	347.000	585.900	215.000	10.635	9.560	0.255	0.226	14.193	0.106	34.479	64.697
SPU17	Mohuddinagar	Rajajaan	7.010	770.000	1355.200	150.000	10.635	25.807	1.010	0.926	26.925	0.348	47.819	65.710
SPU18	Mohuddinagar	Rajajaan	7.030	742.000	414.400	375.000	7.090	21.033	0.916	1.654	21.569	0.266	55.990	57.789
SPU19	Mohuddinagar	Rajajaan	6.800	1371.000	611.800	335.000	165.200	40.933	2.537	1.165	41.606	0.693	67.161	65.658
SPU20	Mohuddinagar	Domaini	6.960	1136.000	242.900	465.000	38.995	34.140	2.073	0.167	34.316	0.518	67.496	57.669
SPU21	Mohuddinagar	Madudabaad	7.080	697.000	539.000	365.000	10.635	18.928	0.799	0.590	19.782	0.233	50.533	54.056
SPU22	Patori	Patori station	7.250	966.000	519.400	295.000	46.085	27.639	1.312	0.654	28.093	0.382	28.810	59.037

SPU23	Patori	N-Dhamman	6.760	837.000	959.700	420.000	22.635	16.531	0.812	-0.132	16.892	0.198	61.901	45.105
SPU24	Patori	N-Dhamman	7.240	1936.000	795.200	375.000	207.780	48.789	3.690	2.885	57.761	0.953	46.663	70.794
SPU25	Patori	Hattanpur	7.120	592.000	487.900	290.000	14.180	5.765	0.208	0.250	6.338	0.061	67.235	45.733
SPU26	Mohanpur	sarari	6.950	648.000	252.700	250.000	7.090	18.128	0.700	1.150	19.659	0.221	59.996	58.739
SPU27	Mohanpur	sarari	6.970	990.000	706.300	375.000	53.175	15.210	0.695	0.163	16.698	0.179	63.996	46.507
SPU28	Mohanpur	sarari	7.100	1407.000	837.200	375.000	184.340	42.880	2.907	0.566	45.834	0.751	70.663	64.512
SPU29	Mohanpur	Mohanpur Dih	6.480	1143.000	396.900	495.000	63.810	20.636	1.157	-0.018	21.572	0.260	77.775	45.838
SPU30	Mohanpur	Mohanpur Dih	6.680	1067.000	976.500	460.000	74.445	15.161	0.767	-0.428	15.836	0.179	72.823	42.476
SPU31	Mohanpur	Baghra	6.860	1013.000	453.600	480.000	46.085	13.822	0.703	-1.029	14.509	0.160	74.997	40.104
SPU32	Mohanpur	Baghra	6.940	1028.000	693.000	450.000	46.085	10.542	0.500	-1.236	11.480	0.118	69.997	38.240
SPU33	Mohanpur	Dumri North	7.090	632.000	984.900	295.000	10.635	11.896	0.464	0.452	12.789	0.135	71.183	49.535
SPU34	Mohanpur	Jalalpur	6.950	851.000	800.100	335.000	42.540	21.535	1.005	0.660	23.095	0.274	47.757	53.309
SPU35	Mohanpur	Dashra	7.080	629.000	746.900	315.000	10.635	7.661	0.294	-0.149	8.678	0.083	66.663	44.013
SPU36	Mohuddinagar	Kurshaha	7.220	361.000	709.100	270.000	10.635	24.125	0.804	0.329	25.236	0.318	40.621	68.668
SPU37	Mohuddinagar	Tetarpur	7.000	1009.000	719.600	195.000	74.445	59.988	4.187	3.763	60.471	1.499	51.278	88.389
SPU38	Mohuddinagar	Baikunthpur	7.100	1196.000	442.400	455.000	81.535	33.682	1.844	3.490	35.357	0.508	49.937	65.628
SPU39	Mohuddinagar	Dubha Paschim	7.380	567.000	595.700	435.000	10.635	2.584	0.100	-0.899	3.814	0.027	75.883	36.856
SPU40	Mohuddinagar	Bochha	7.130	1395.000	440.300	260.000	164.000	52.168	3.682	2.870	52.796	1.091	64.909	76.736
SPU41	Vidyapatinagar	Bajitpur	6.880	923.000	646.100	360.000	35.450	13.971	0.616	0.463	15.783	0.162	80.553	47.050
SPU42	Vidyapatinagar	Bangraha	6.150	821.000	574.700	365.000	14.180	15.863	0.720	0.565	17.402	0.189	83.559	48.188
SPU43	Vidyapatinagar	Bangraha	6.900	946.000	662.200	340.000	35.450	26.166	1.307	1.770	27.323	0.354	69.114	57.955
SPU45	Vidyapatinagar	Kancha	7.070	795.000	556.500	340.000	10.635	13.122	0.557	1.367	14.524	0.151	73.526	49.637
SPU46	Vidyapatinagar	Kancha	7.500	161.900	113.330	76.000	10.635	4.179	0.076	-0.316	5.093	0.044	14.781	73.269

*Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total hardness (TH), Chloride Hazard (Cl^-), Soluble Sodium Percentage (SSP), Sodium Absorption Ratio (SAR), Residual Sodium Carbonate (RSC), Na% (Sodium Percent), MH (Magnesium hazard), KR (Kelly's ratio) and PI (Permeability index).